DETERMINATION OF WATER RATES OF SMALL ENGINES BY CLAYTON'S METHOD

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A THESIS

PRESENTED BY

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LINCOLN W. LUCKOW

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TO THE

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ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING

MAY 25, 1916

H M Raymond

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26435

Determination of the Water Rates of Small Engines by Clayton's Method.

Introduction:

The subject chosen for thesis was "Determination of the Water rates of Small Engines by Clayton's Method". Determinations of the exhaust qualities of the different engines under various loads were found in connection with the water rate determinations.

Preliminary:

It was found by Clayton and published in his book, " A New Analysis of the Cylinder Performance of Reciprocating Engines " that the water rates of reciprocating engines could be approximated with very little error by the indicator card. A certain relation existing between the value of n for the expansion PV^n and the quality at cut-off enabled him to determine the water rate of an engine. He found that with a cylinder having a tight-fitting piston the expansion follows the law $PV^n = C$. The curve of which this is the equation becomes a straight line when plotted on logarithmic paper. This can be proved by mathematics.

$$PV^n = P_1V_1^n = C$$

$$\log P + n \log V = \log P_1 + n \log V_1$$

$$n (\log V - \log V_1) = \log P_1 - \log P$$

$$n = \frac{\log P_1 - \log P}{\log V - \log V_1}$$

The value of n can be obtained from the log diagram by measuring the vertical and horizontal distances between two points on the expansion curve, which is a straight line, with a uniformly graduated scale. The value of n is equal to the distance along the pressure axis divided by the distance along the volume axis. The quality at cut-off is equal to the weight of saturated steam at cut-off divided by the weight of steam per stroke(found from the total amount of steam used) and the steam in the clearance space.

Experiments conducted by Clayton were made on relatively large-sized cylinders, all of which were above 15 inches in diameter with but a few exceptions. The diameter of the largest cylinder tested in the performance of this thesis was 9 inches. These experiments were made to determine the relation between x_c and n for small engines.

Body:

The general mode of procedure was as follows: All of the engines were tested at four loads: friction, quarter, half, and full loads. In

order to determine the quality of inlet and exhaust steam a throttling calorimeter was placed above the cylinder and a separating calorimeter was placed on the exhaust side. The steam consumption was found by weighing the steam which was condensed in a surface condenser. The inlet and exhaust pressures were kept approximately constant, inlet pressure about 100# gauge and exhaust about 5# gauge. The connections to the indicators were made as short as possible. The reducing motion employed for all of this work was of the pantograph type which insured the proper motion to the indicator drum.

After the engine had been running with friction load, i.e. brake removed, until conditions were steady, the run was started. The following readings were taken every ten minutes: R.P.M., inlet pressure, exhaust pressure, throttling calorimeter temperature, separating calorimeter, and weight of condensed steam. Indicator cards were taken at regular intervals. The reading of the barometer was recorded for each series of tests. Fig. 1 is a sample of the running log taken for the test on the Phoenix engine.

After the run was completed the

indicator springs and the pressure gauges were calibrated. The indicator cards were integrated with a planimeter and the areas were listed on a log sheet. The average card was then taken for each load and the I.H.P. under that load determined. Before the card could be transferred to the log diagram the head and crank end clearances of the engine had to be found. This was accomplished by the simple method of filling the clearance space with water. After securing the clearance, it was then laid off to the same scale as that of the indicator card, an inch on the card horizontally representing a definite number of cubic feet. The line of absolute zero pressure is also drawn on the average card. The total volume, represented on the indicator card by the distance from the clearance line to the other end of the stroke along the abscissa, is then divided into a definite number of parts. The volumes at the various parts of the stroke together with the absolute pressures were then transferred onto the log diagram. The log diagram gave a straight line for the expansion curve and the slope of this line determined the value of n. The quality at cut-off was found

as already explained in a previous paragraph.

In order to study how the steam consumption per hour varied with the I.H.P. the Willans line was drawn. This, for most reciprocating engines is a straight line when the ordinates are steam consumption per hour and I.H.P.

I. The first engine to be tested was an 8" x 9" vertical Wachs engine of the side-crank type. A centrifugal fly-ball throttling governor was the means of adjusting the speed by changing the pressure. Before commencing the run the bearings were tightened and the D-slide-valve was set to give equal cut-offs. The engine was allowed to run with brake removed until the temperature conditions became constant. The first load under which the engine was run was the friction load. The run lasted one hour and during that time the readings already mentioned were made. Runs under quarter, half, and full load were then made, the engine developing about 12 I.H.P. at full load.

The curve showing the relation of quality at cut-off to n was a line which sloped slightly downward, showing that as n increases there is a decrease of x_c. As this engine is a

constant cut-off throttling engine the cut-off is fixed and expansion takes place for only a short part of the stroke. Wire-drawing was very pronounced on all of the indicator cards taken from this engine. The Willans line checked up fairly close with what was expected. The curve showing the relation of the quality of exhaust to the I.H.P. indicated a decrease in quality with an increase in load.

II. The second engine to be tested was an 8 1/2" x 10" high-speed, single cylinder, piston-valvePhoenix engine. The percentage of cut-off was governed by an automatic shaft governor. As in the preceding case the engine was run at four loads, the maximum I.H.P. being about 35 H.P.

The x_c and n curve showed a slight slope downward, simulating the curve for the Wachs engine. The points for the Willans line laid on a straight line. The curve showing the relation of quality of exhaust to the I.H.P. proved to be a curve sloping downward as for the Wachs engine.

III. The low pressure cylinder of a

cross-compound Corliss engine was disconnected from the engine and the high-pressure cylinder was used for the third test. The engine speed and the percent of cut-off were controlled by a fly-ball governor. The size of the engine was 9" x 24". Dashpots are used on the steam inlet valves to effect sharp cut-offs. The lengths of the governor rods were changed for each run in order to equalize cut-offs. The engine was run at four loads, the engine developing 27 I.H.P. for its maximum.

The x_c and n curve gave a line with an upward slope. This was directly opposite to the lines obtained for the Wachs and the Phoenix engines. The points found by experiment agreed very closely with those found by Clayton in his tests on Corliss engines. This result was expected as most of the engines tested by Clayton were of the Corliss type. The Willans line did not check up very satisfactorily. As in the two previous tests the quality of exhaust decreased as the I.H.P. of the engine increased.

Conclusion:

It was attempted to plot the various values of x_c and n for the different engines on the same sheet as was done by Clayton. The result showed that engines of such unlike characteristics as tested in these series of experiments could not give a line which ould be used for determining water rates of small engines. As the three engines ran at widely different speeds the slopes of the lines were different and the average slope could not be used. Clayton found in his experiments a new line for each different speed at which the same engine was run.

The curves of I.H.P. and exhaust quality all had the same characteristics; i.e. the quality of exhaust decreased as the I.H.P. increased. This introduced something contrary to what has always been considered the case. This new relation could not be explained from all the theoretical discussion which was given to it. The only solution or explanation offered for this apparent contradiction is that the engines were small.

This investigation showed that the relation between x_c and n for the engines tested was different from that obtained by Clayton.

The water rates of small engines can not be computed from Clayton's results. Each individual small engine would require its own curves if its water rate was to be determined from an indicator card.

Fig. 1

RUNNING LOG OF TEST MADE ON PHOENIX

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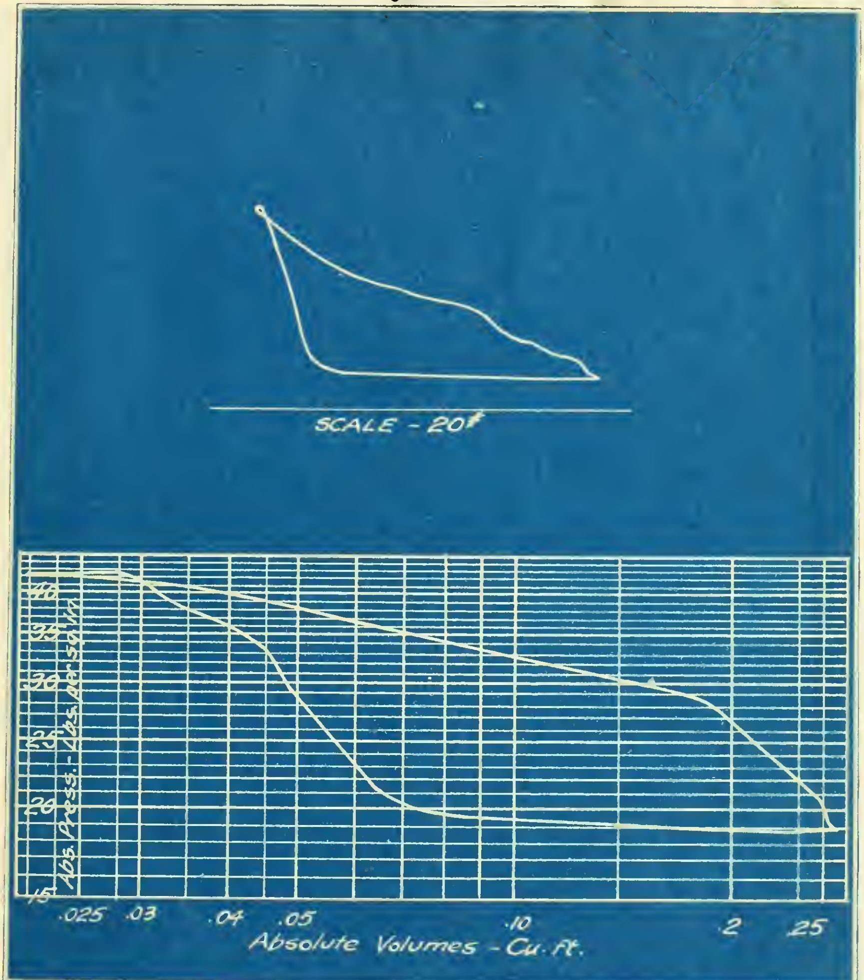
RUNNING LOG OF TEST MADE ON PHOENIX

TIME	R.P.M.	BRAKE LOAD	INLET PRESS.	CALOR. TEMP.	WATER IN SEP. CALOR.	STEAM IN SEP. CALOR.	COND. STEAM
2:21	302.5	0	89	232	.093	32.06	550
2:31	303.	"	90	232			
2:41	303.	"	90	232			
2:51	302.5	"	91	233			818
3:01	"	"	92	233			
3:11	"	"	96	242			
3:21	"	"	82	237	.270	35.27	1092
Aver.	302.6	"	90	234.5	.177	3.21	542
4:21	300.	50	91	232	.138	35.27	531
4:31	302.	"	90	232			
4:41	302.	"	95	233			
4:51	301.5	"	98	234		36.41	948
5:01	"	"	102	237	.228		
5:11	"	"	96	239	.052		
5:21	"	"	96	232	.125	37.78	1361
Aver.	301.4	50	95.5	234	.163	2.51	830
5:35	303	75	98	231	.065	37.78	531
5:45	303	"	110	233			
5:55	301	"	112	240			
6:05	304	"	110	242			1087
6:15	304	"	110	237			
6:25	304	"	112	238	.204	39.68	1456
Aver.	303.2	75	108.6	237	.139	1.90	925
6:40	301	150	112	242	.036	27.38	530
6:50	301	"	105	240			
7:00	301	"	100	235			
7:10	300	"	95	228			
7:20	303	"	104	229	.211	28.63	1640
7:30	300	"	100	234	.085		543
7:40	296	"	100	230	.133	28.96	1102
Aver.	300	150	102.3	234	.223	1.58	1669

Barometer – 29.50" Hg.

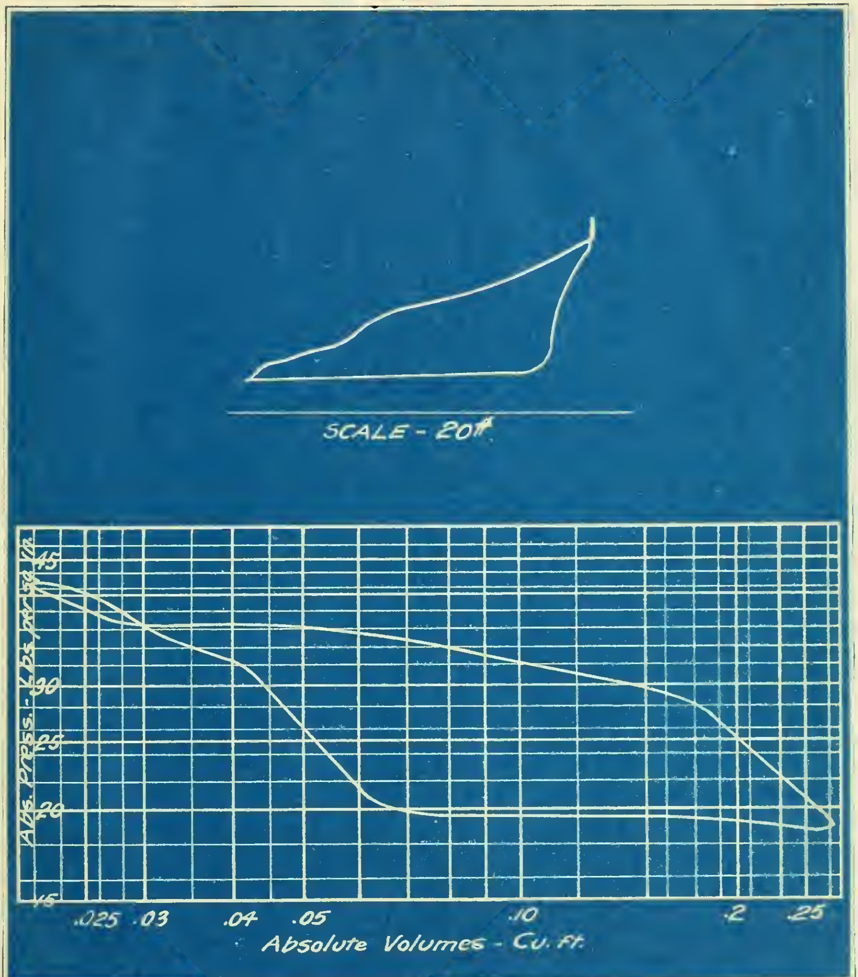
Fig. 1

Fig. 2



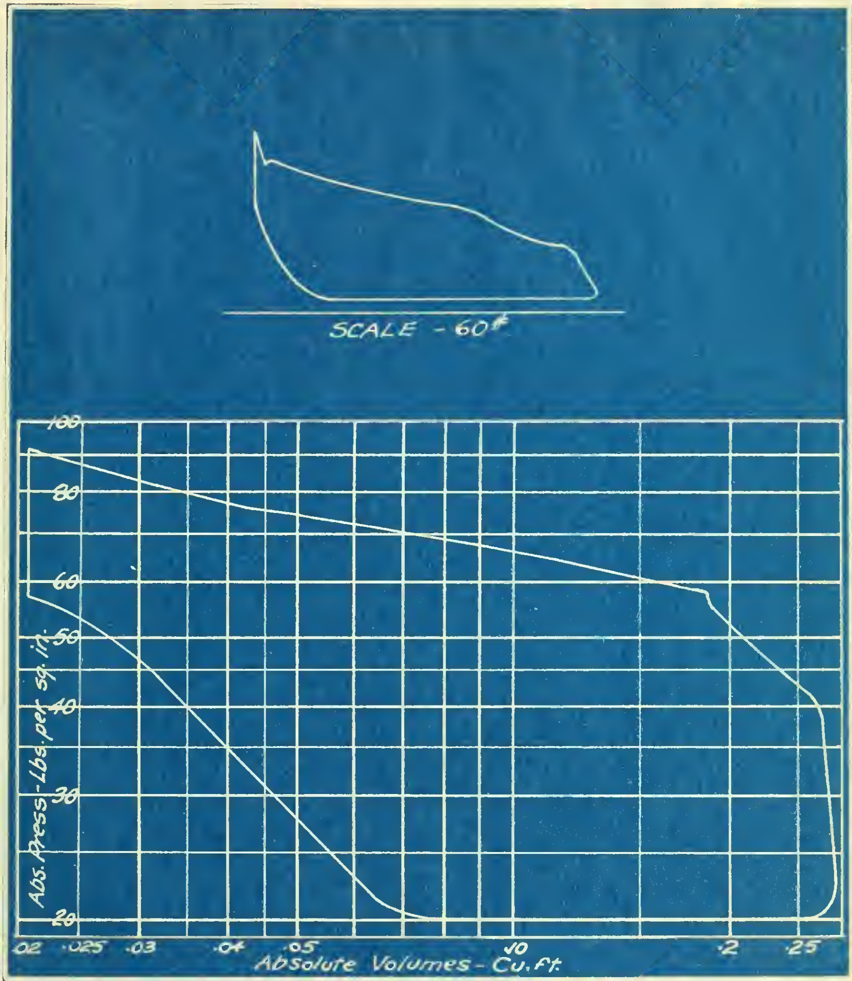
HEAD END CARD FOR 8"x9" WACHS ENG. 1/4 LOAD.

Fig. 3



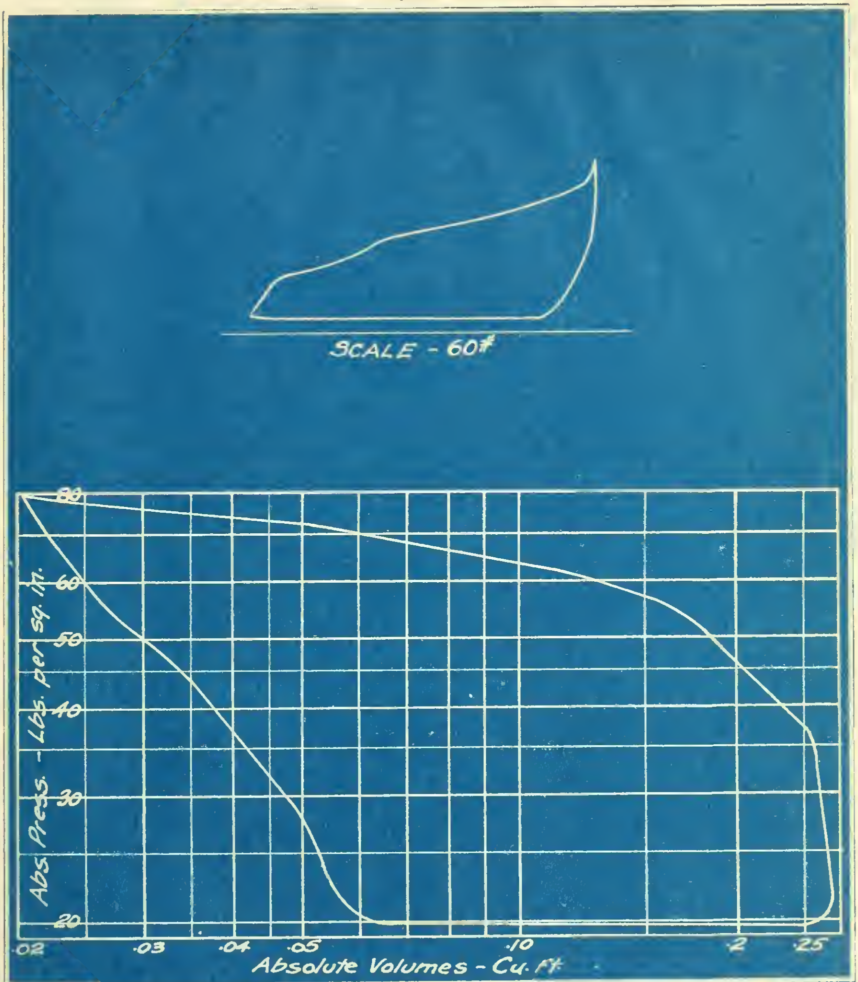
CRANK END CARD FOR 8"×9" WACHS ENG. 1/4 LOAD.

Fig. 4



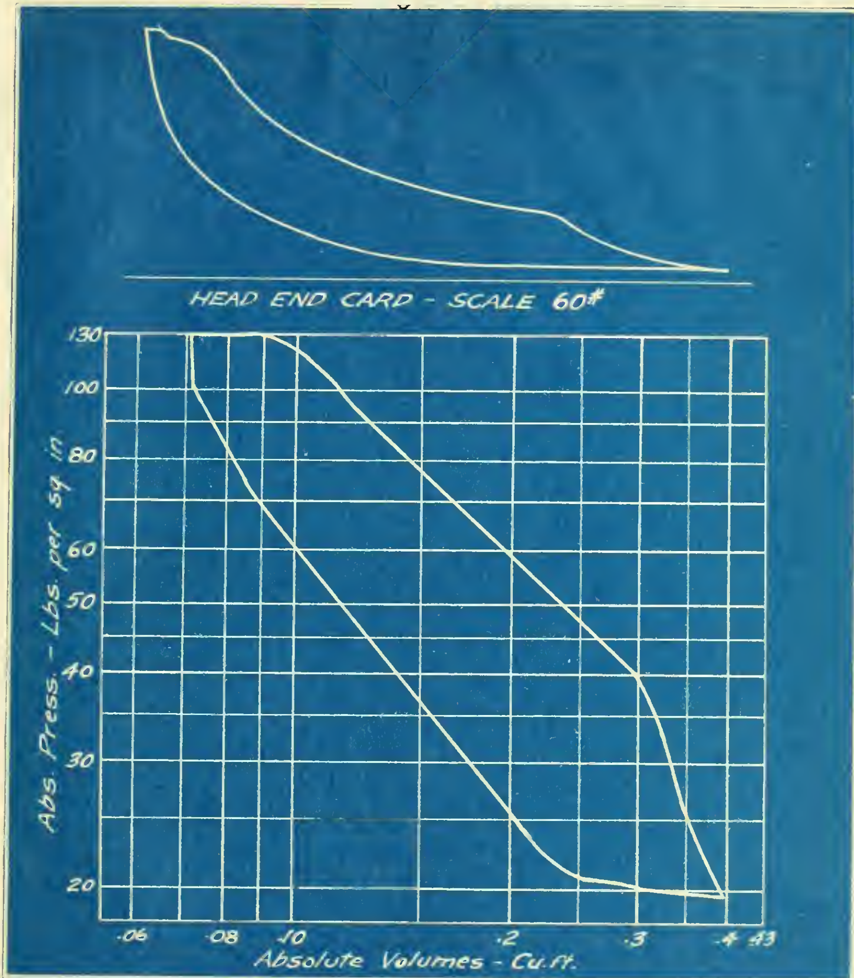
HEAD END CARD FOR 8"x 9" WACHS ENGINE. FULL LOAD.

Fig. 5



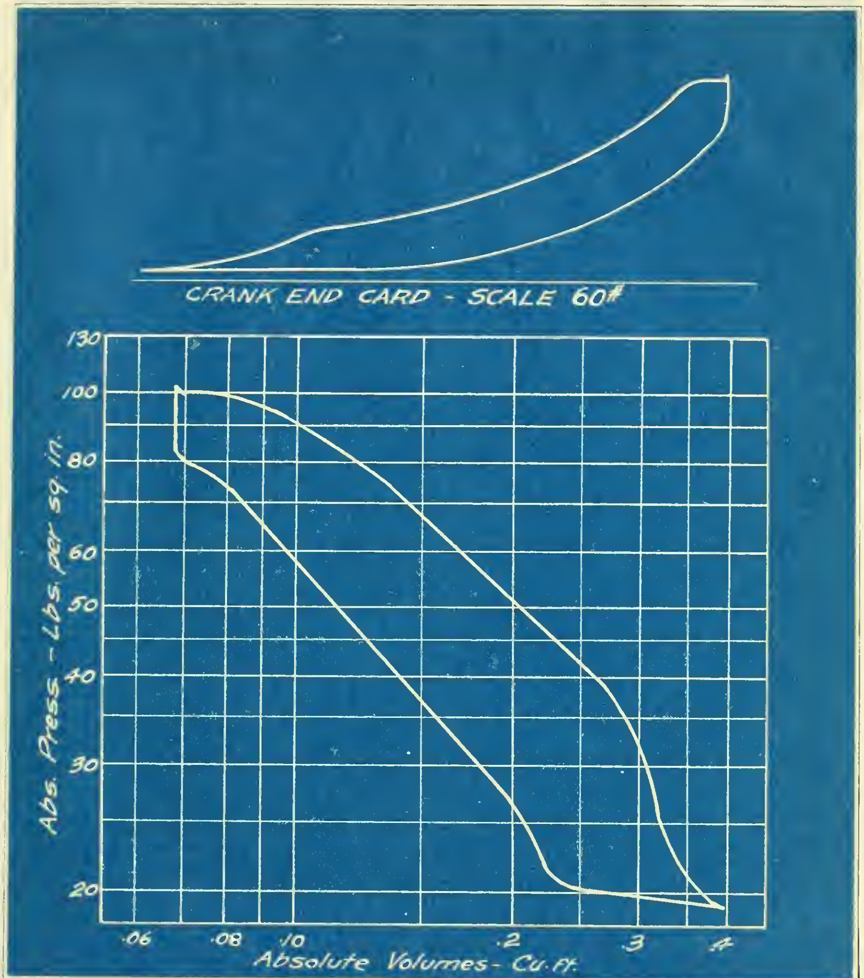
CRANK END CARD FOR 8" x 9" WACHS ENGINE. FULL LOAD.

Fig. 6



8½" x 10" PHOENIX ENGINE. HALF LOAD.

Fig. 7



8½"×10" PHOENIX ENGINE - HALF LOAD.

Fig. 8

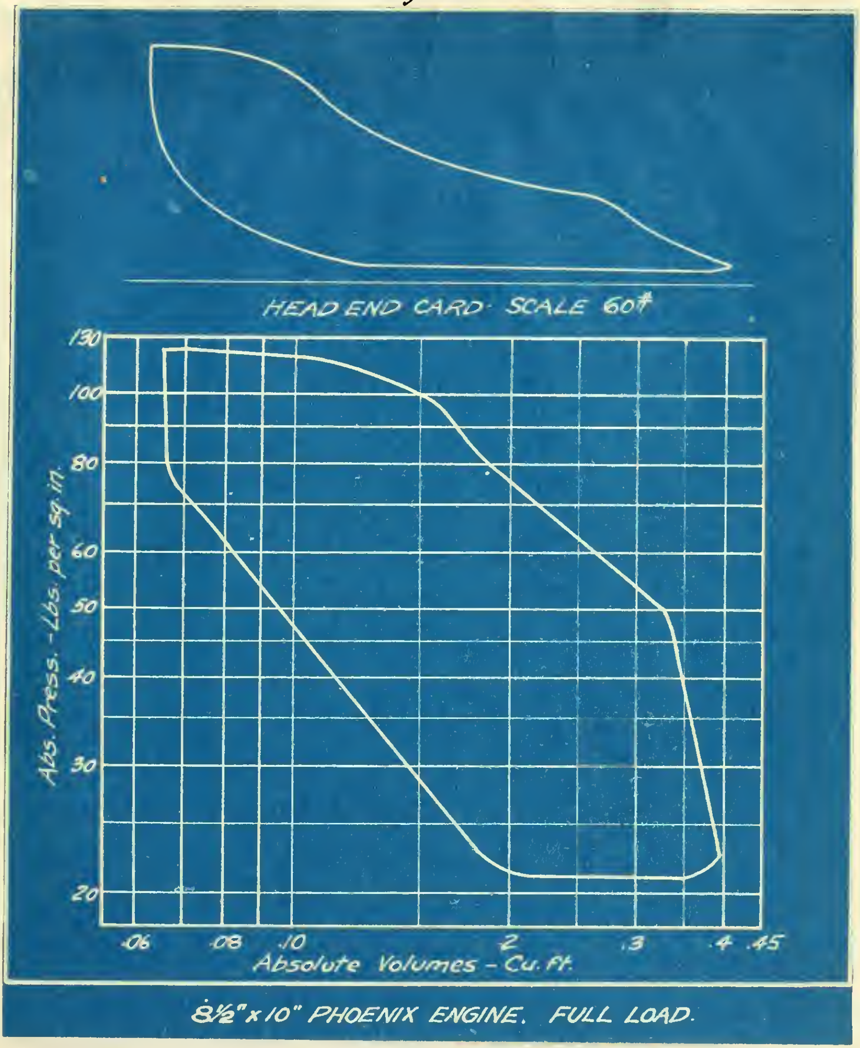
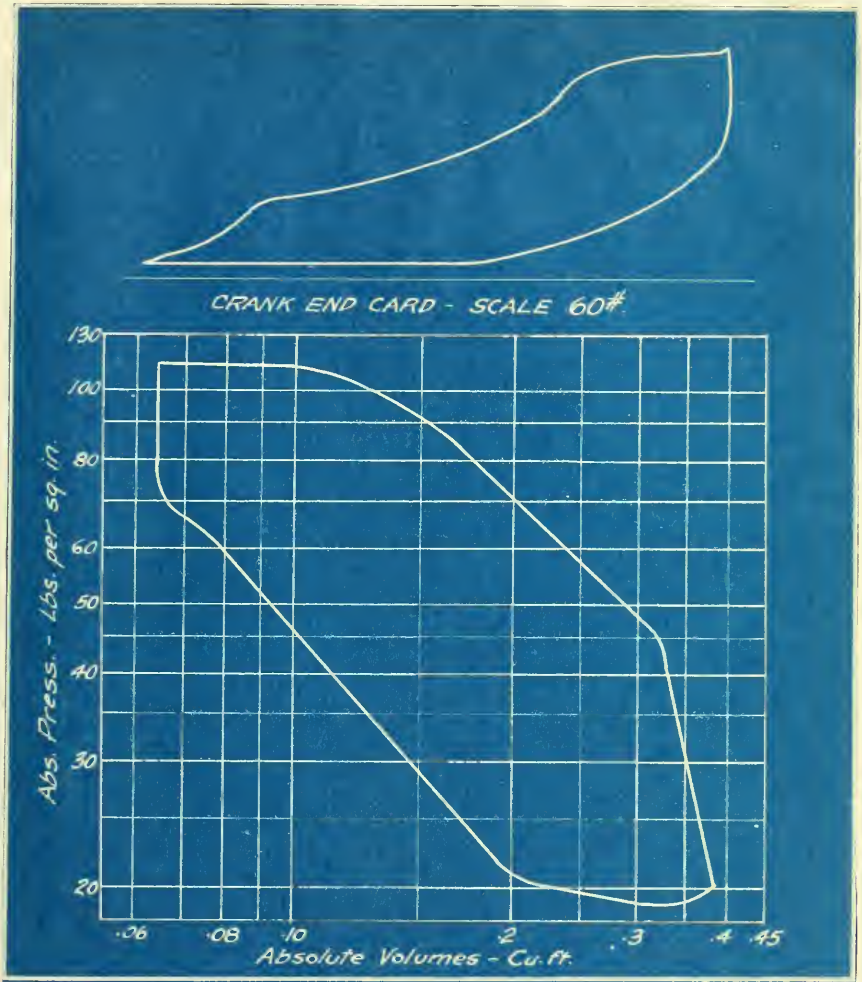
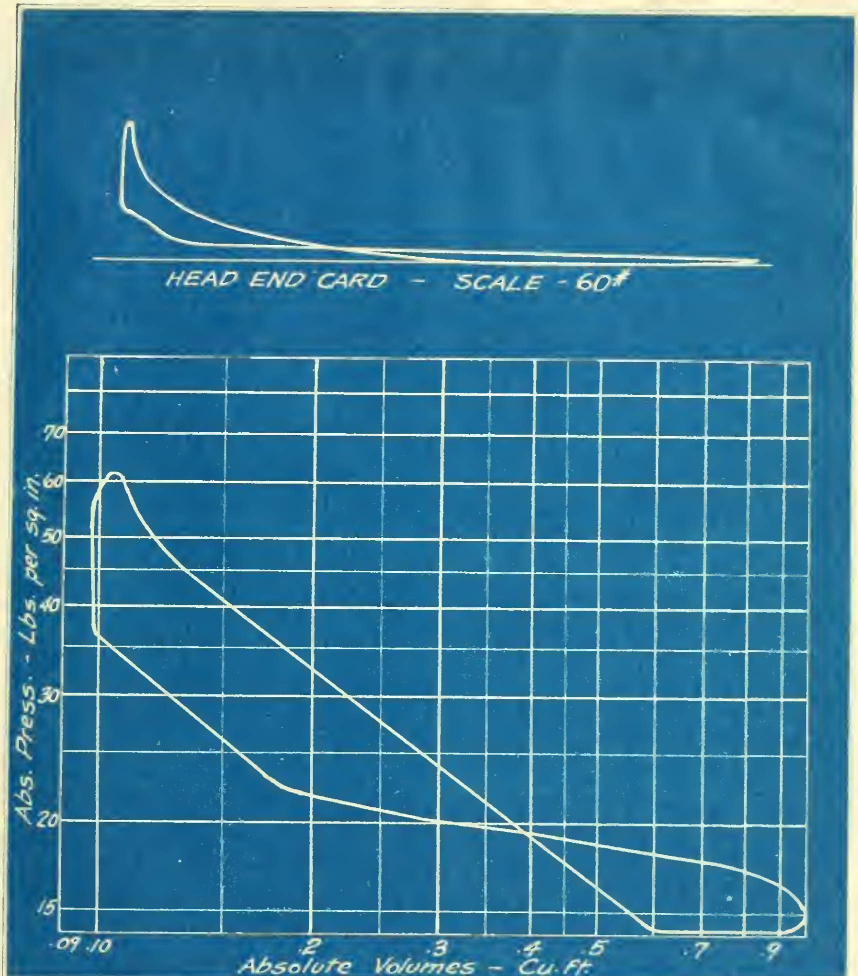

HEAD END CARD SCALE 60#
130
100
80
60
50
40
30
20
Abs. Press. - Lbs. per sq. in.
.06
.08
.10
.2
.3
.4
.45
Absolute Volumes - Cu. Ft.
8½" x 10" PHOENIX ENGINE. FULL LOAD.

Fig. 9



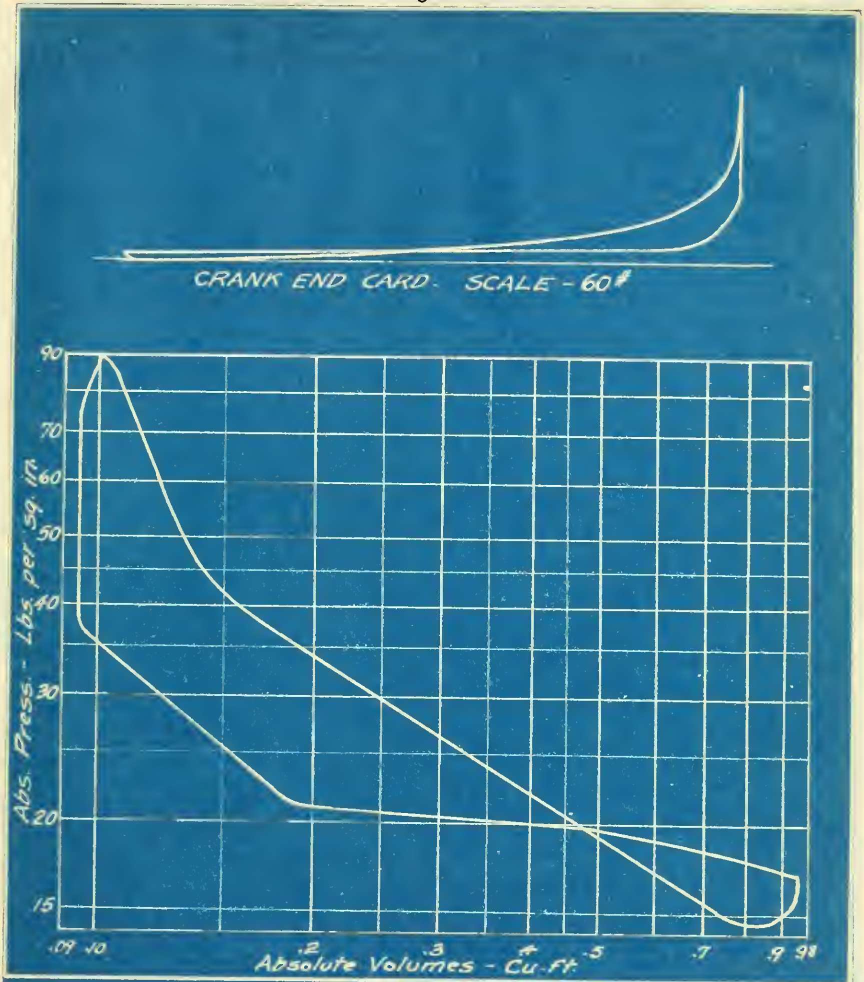
8½" x 10" PHOENIX ENGINE. FULL LOAD.

Fig. 10



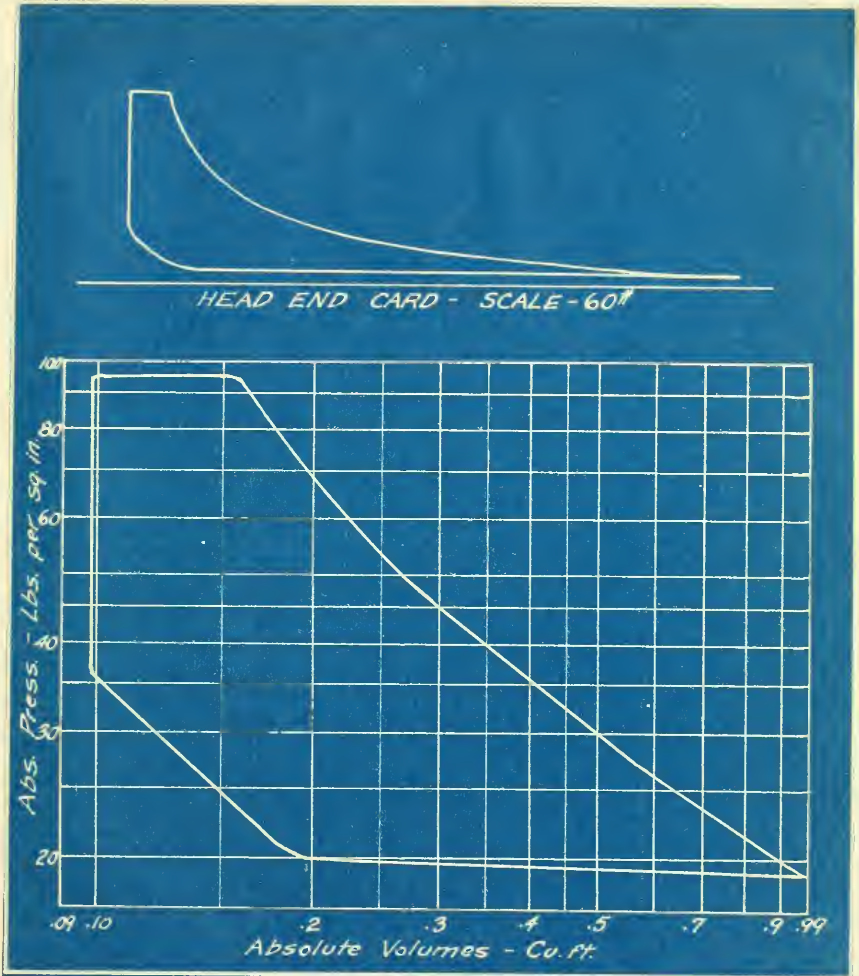
9"x 24" CORLISS ENGINE. FRICTION LOAD.

Fig. 11



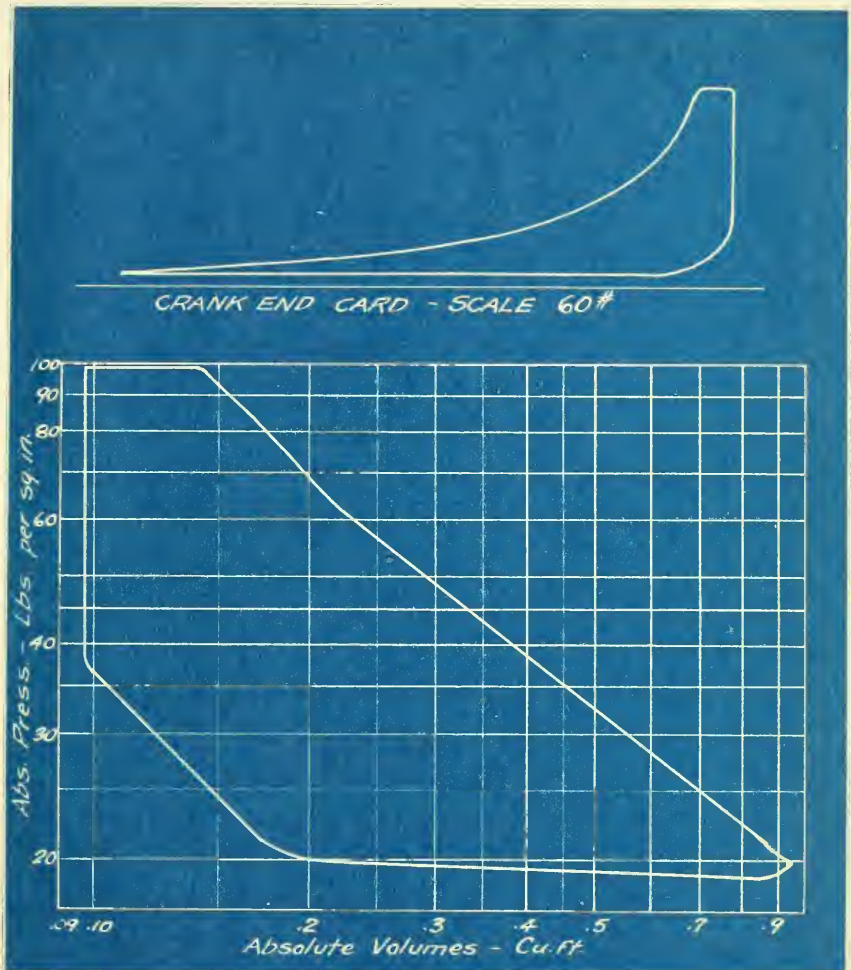
9"x 24" CORLISS ENGINE. FRICTION LOAD.

Fig. 12



9" x 24" CORLISS ENGINE. HALF LOAD.

Fig. 13



9" x 24" CORLISS ENGINE. HALF LOAD.

Fig. 14

Fig. 14

8" x 9" WACHS					
LOAD	I.H.P.	X_c	n	X_I	X_E
FRICTION	.56	.81	.992	.96	.95
QUARTER	2.78	.764	.89	.963	.91
HALF	5.37	.78	.931	.966	.935
FULL	11.72	.697	.995	.968	.90

8½" x 10" PHOENIX					
LOAD	I.H.P.	X_c	n	X_I	X_E
FRICTION	3.66	.586	.86	.97	.948
QUARTER	12.10	.557	.87	.97	.94
HALF	19.81	.533	.93	.97	.933
FULL	34.85	.568	.88	.97	.896

9" x 24" CORLISS					
LOAD	I.H.P.	X_c	n	X_I	X_E
FRICTION	1.52	.361	.69	.97	.946
QUARTER	5.82	.472	.78	.97	.923
HALF	13.0	.495	.79	.972	.872
FULL	26.82	.557	.94	.973	.822

Fig. 14

Fig. 15

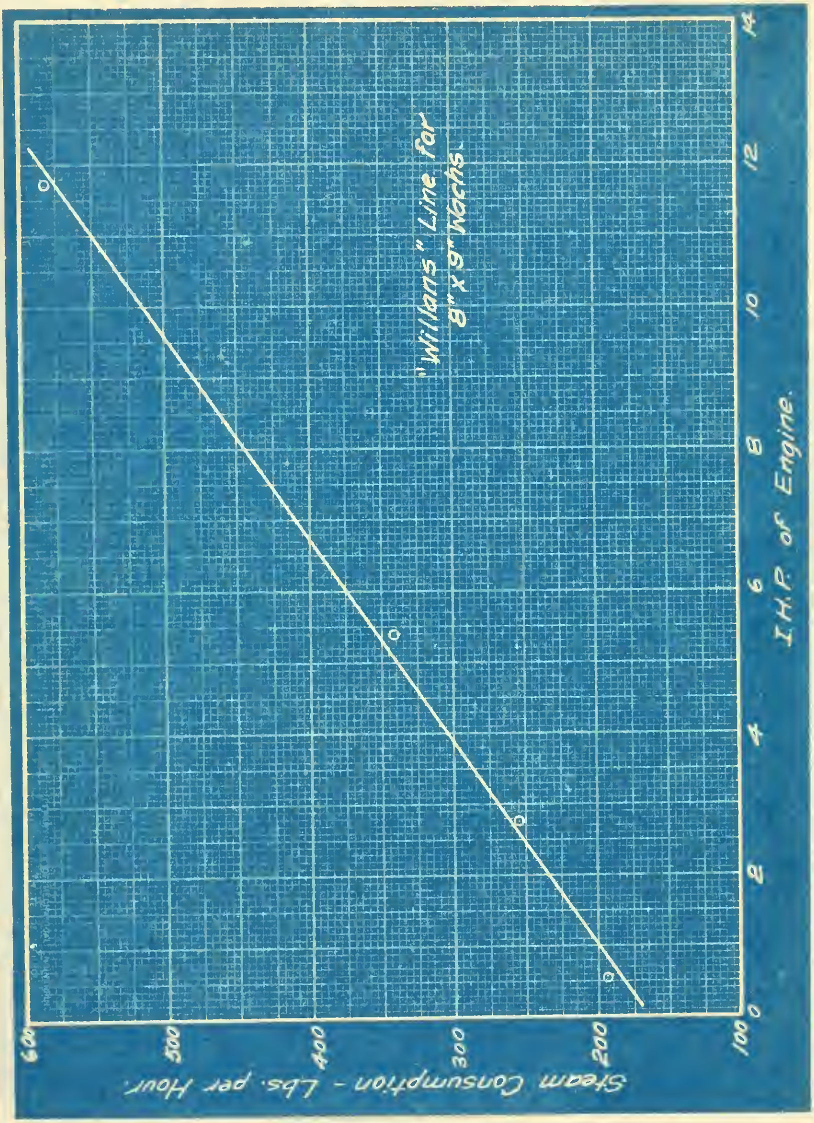

"Willans" Line for
8" x 9" Wachs.
I.H.P. of Engine.
0
2
4
6
8
10
12
14
Steam Consumption - Lbs. per Hour.
100
200
300
400
500
600

Fig. 16

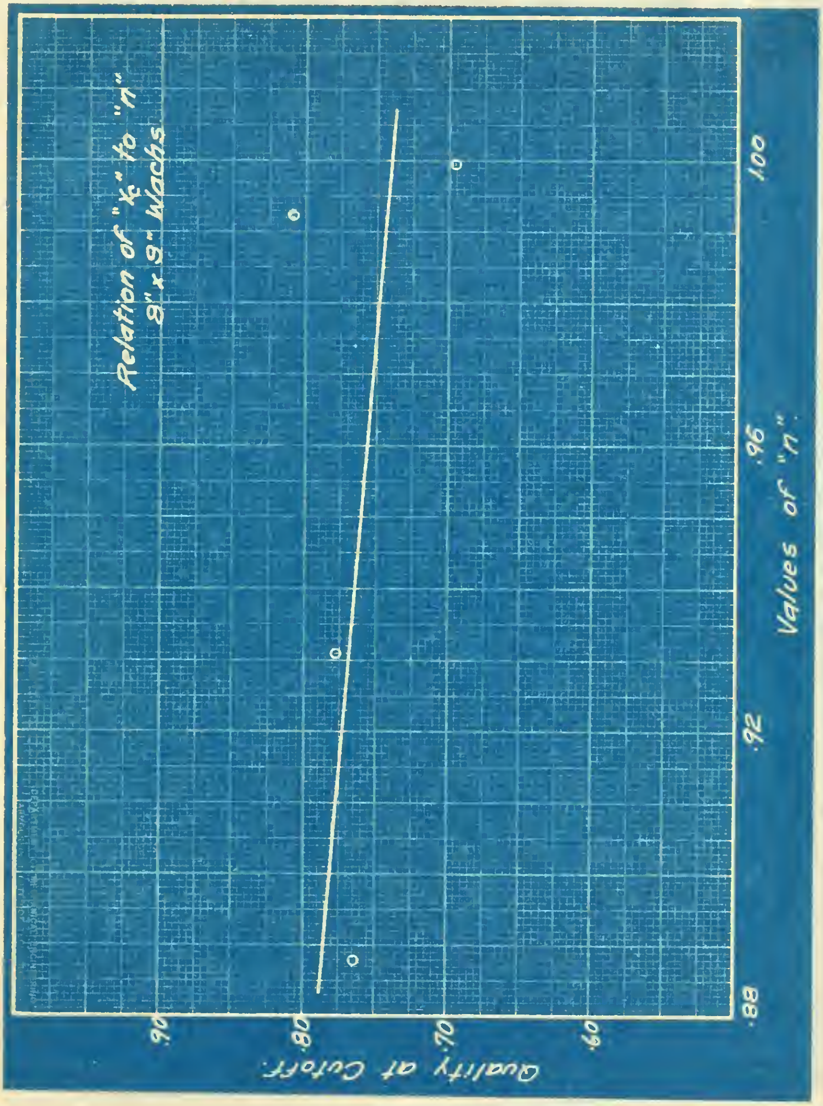
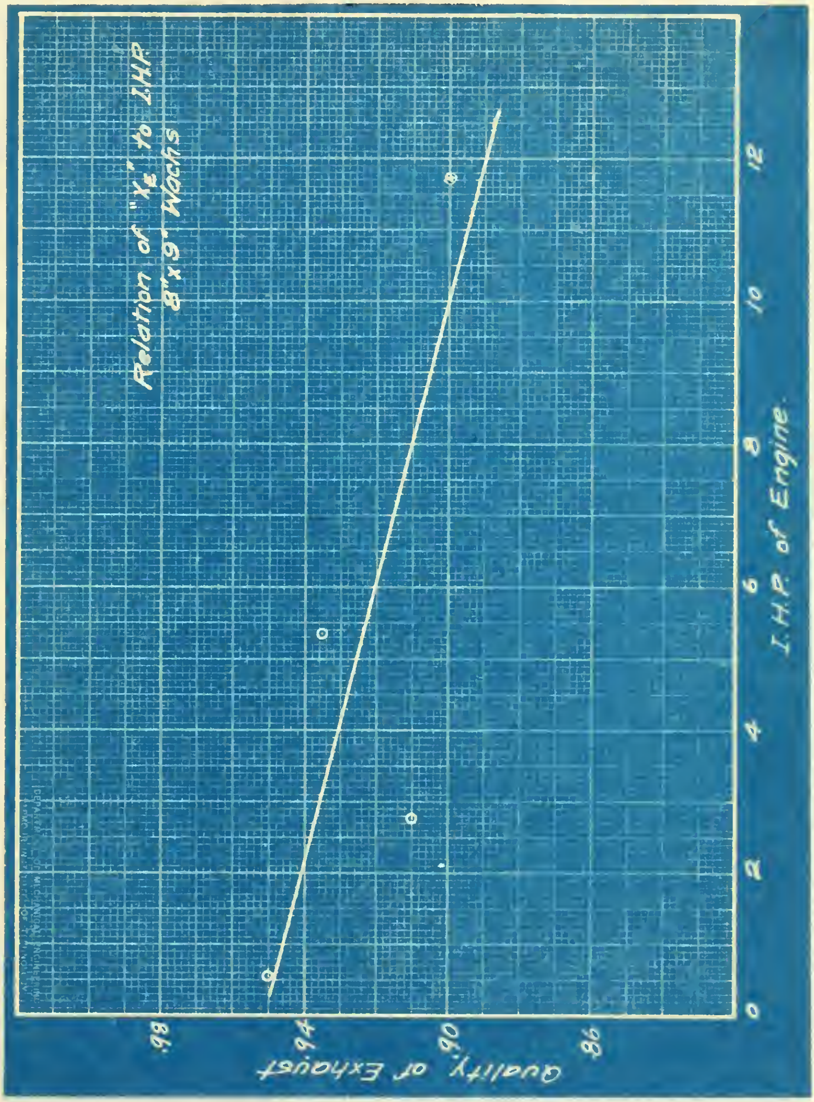

Relation of "x_c" to "n"
8" x 9" Wachs
Values of "n"
.88
.92
.96
1.00
Quality at Cutoff.
.90
.80
.70
.60

Fig. 17



Relation of "X_E" to I.H.P.
8"x9" Wachs
I.H.P. of Engine
0
2
4
6
8
10
12
Quality of Exhaust
.98
.94
.90
.86

Fig. 18

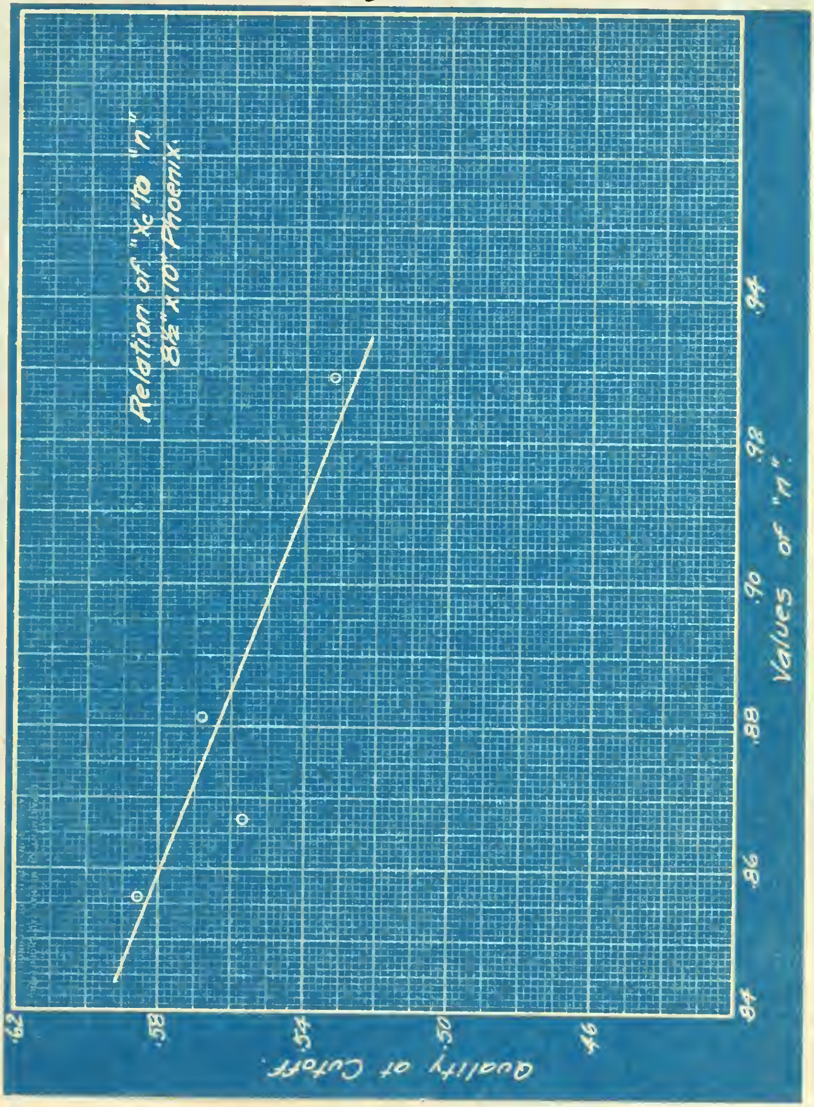

Relation of "Xc" to "n"
8½" x 10" Phoenix.
Values of "n".
.84
.86
.88
.90
.92
.94
Quality of Cutoff.
.62
.58
.54
.50
.46

Fig. 19

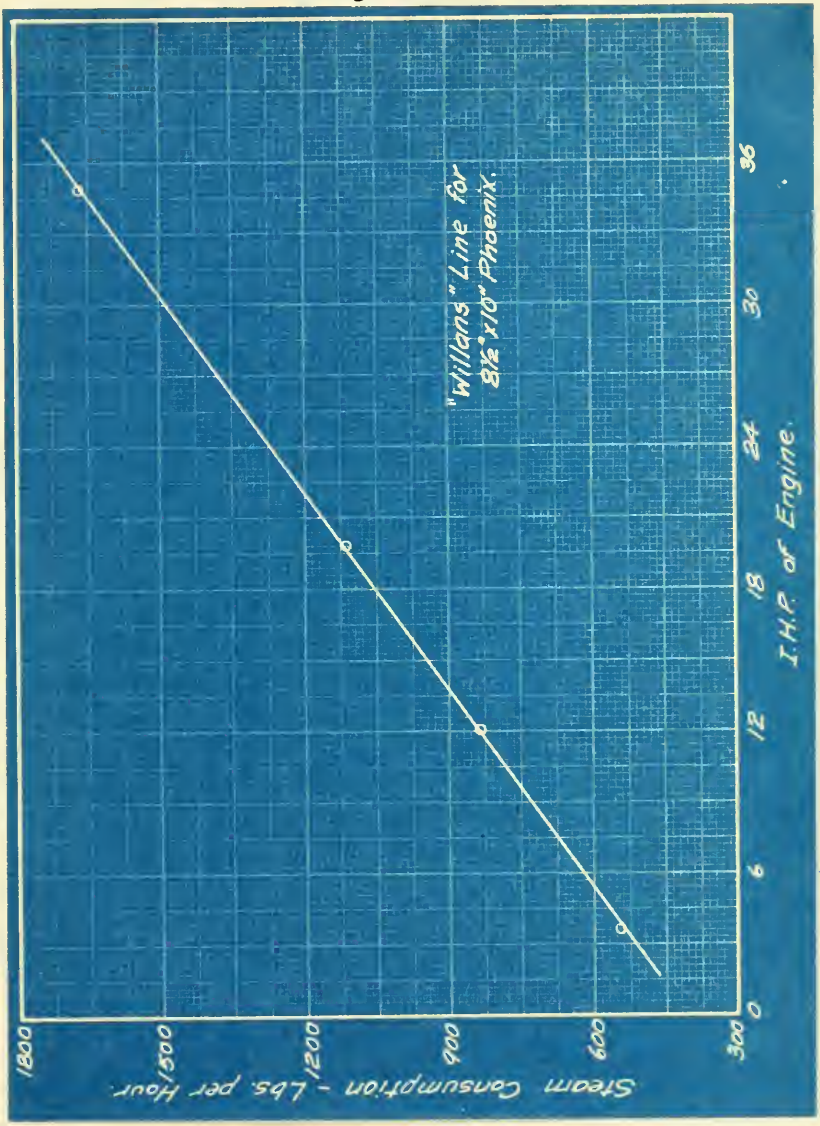
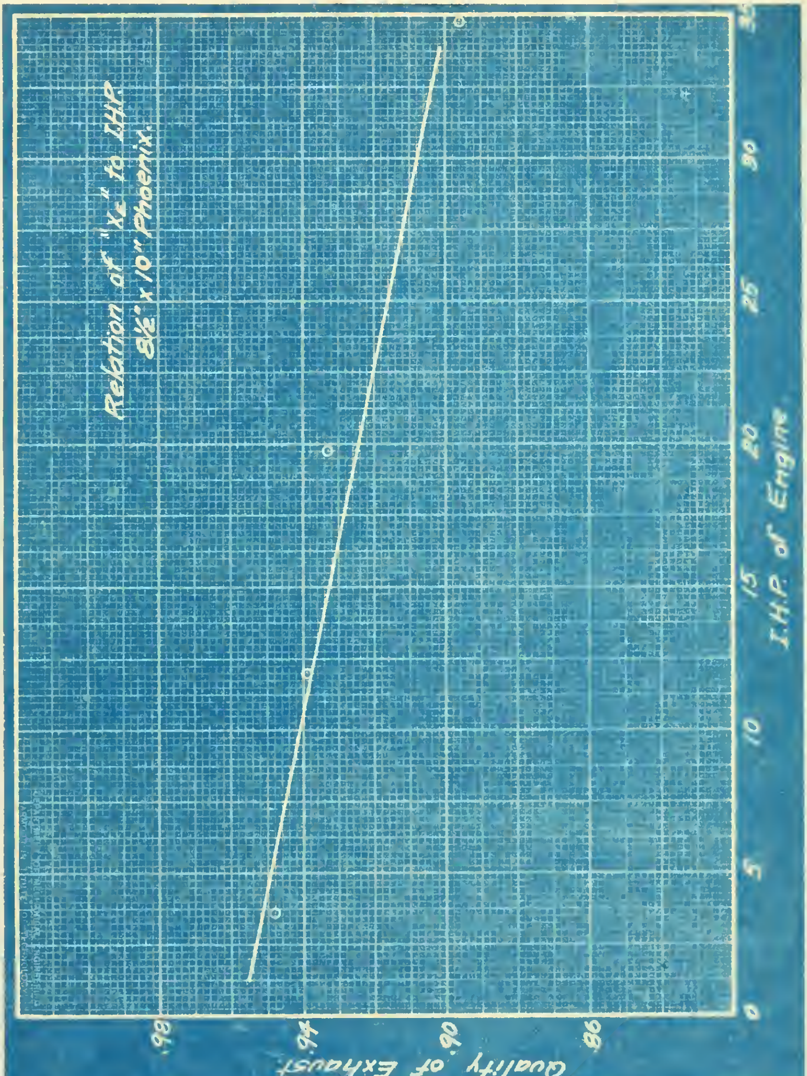
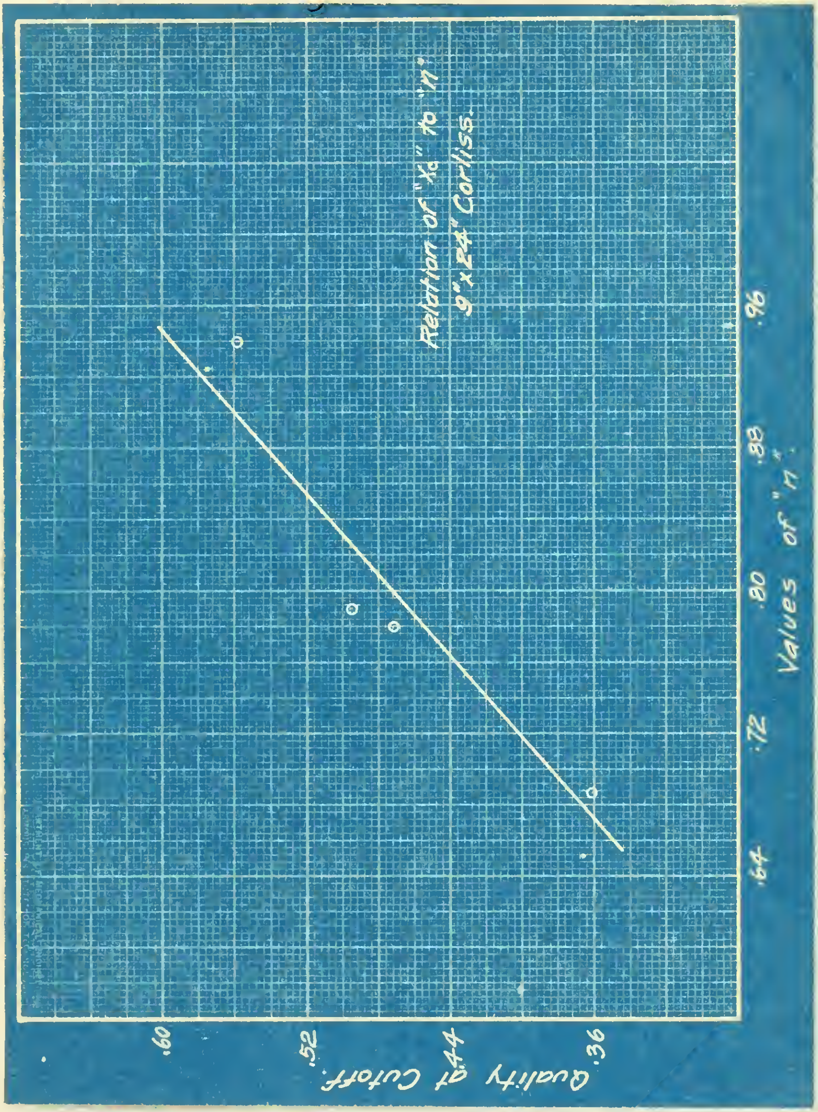

"Willans" Line for
8½"x10" Phoenix.
I.H.P. of Engine
0
6
12
18
24
30
36
Steam Consumption - Lbs. per Hour.
300
600
900
1200
1500
1800

Fig. 20



Relation of "x2" to I.H.P.
8½" x 10" Phoenix.
I.H.P. of Engine
0
5
10
15
20
25
30
35
Quality of Exhaust
.98
.94
.90
.88

Fig. 21



Relation of "Xa" to "n"
9"x24" Corliss.
Values of "n".
.64
.72
.80
.88
.96
Quality at Cutoff.
.36
.44
.52
.60

Fig. 22

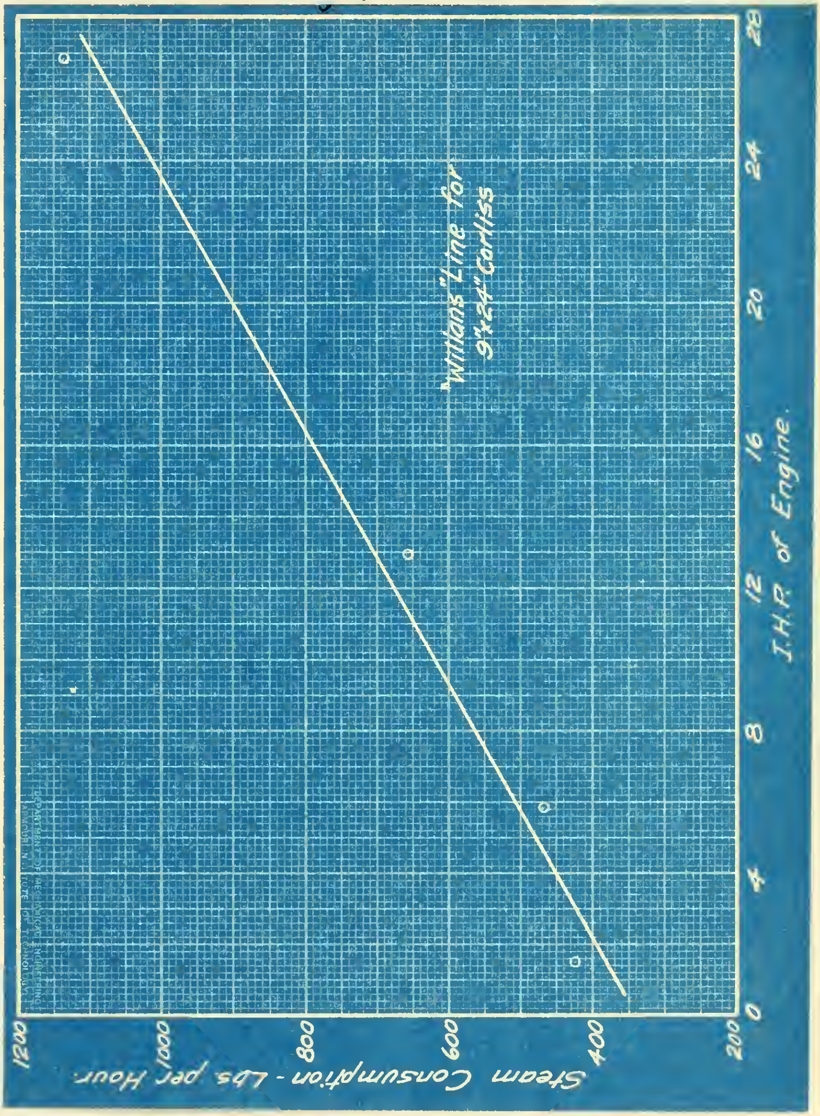
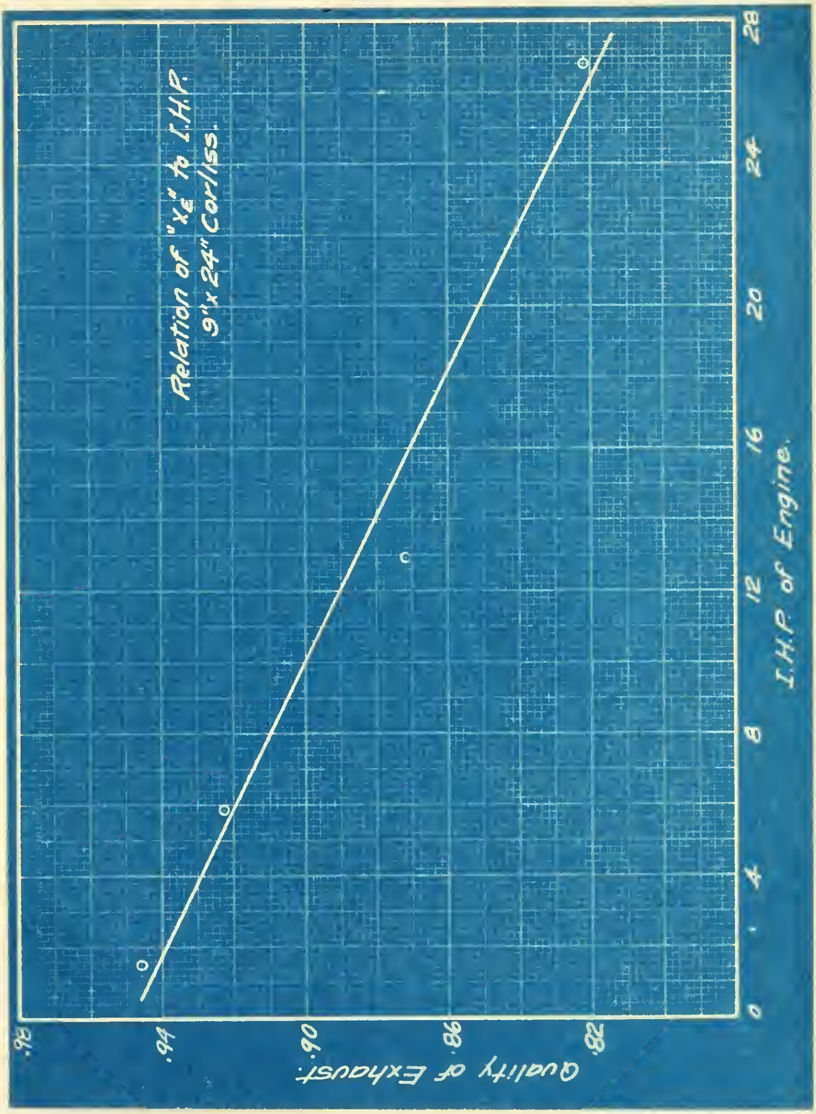
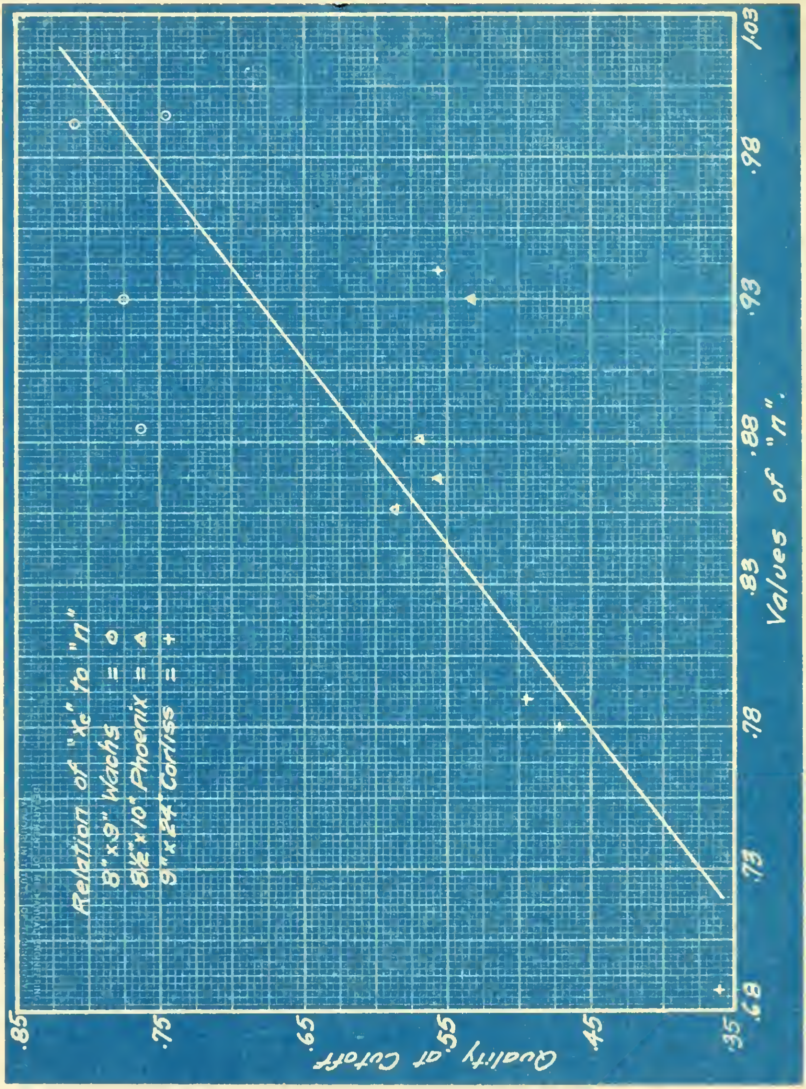

"Willans" Line for
9"x24" Corliss
I.H.P. of Engine.
Steam Consumption - Lbs per Hour.
0
4
8
12
16
20
24
28
200
400
600
800
1000
1200

Fig. 23



Relation of "x_E" to I.H.P.
9"x24" Corliss.
0
4
8
12
16
20
24
28
I.H.P. of Engine.
.96
.94
.90
.86
.82
Quality of Exhaust.

Fig. 24



Relation of "x_c" to "n"
8"x9" Wachs = ⊙
8½"x10" Phoenix = △
9"x24" Corliss = +
Values of "n"
.68
.73
.78
.83
.88
.93
.98
1.03
Quality at Cutoff
.35
.45
.55
.65
.75
.85